Intracranial Solitary Fibrous Tumors: A Heterogeneous Entity with an Uncertain Clinical Behavior

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BACKGROUND: **Intracranial solitary fibrous tumors (ISFTs) are rare mesenchymal neoplasms originating in the meninges and characterized by very different biologic and clinical behaviors. Benign histotypes, such as hemangiopericytomas, are now considered a cellular phenotypic variant of this heterogeneous group of rare spindle-cell tumors. Owing to their rarity and resemblance to other, more common brain tumors, ISFTs are often poorly recognized and remain a diagnostic challenge.**

METHODS: **We describe a surgical series of 29 patients treated for ISFTs confirmed histologically and through immunohistochemistry. We attempt to provide a focus on the natural history of these pathologies and the need for tailored management.**

RESULTS: **This was a retrospective consecutive series of 29 patients with either solitary fibrous tumor ($n = 14$) or hemangiopericytoma ($n = 15$) over a 10-year period. Mean follow-up time was 37.71 months. Recurrence rate was 42.9% for solitary fibrous tumors versus 26.7% for hemangiopericytomas. *STAT6* expression was 66.7% in hemangiopericytomas versus 42.9% in SFTs.**

CONCLUSIONS: **Histopathology and immunohistochemical staining (characterized by positive expression of mainly *STAT6* but also *CD34*, Bcl-2 protein, and vimentin) are key in diagnosis and management of ISFTs. Although ISFTs are still considered benign lesions with very rare aggressive evolution, their clinical behavior is largely unpredictable. This study highlights the importance of relying on immunohistochemistry for a thorough definition of the management strategy.**

INTRODUCTION

Although solitary fibrous tumors (SFTs) mainly affect the visceral pleura, they are also described in a number of head and neck locations, including the orbit, nasal cavities, paranasal sinuses, thyroid, parotid glands, and buccal and parapharyngeal spaces.[1,2] Klemperer and Rabin[3] first described this rare mesenchymal neoplasm as a primary spindle-cell tumor of the pleura in 1931. A primary intracranial solitary fibrous tumor (ISFT) was first reported by Carneiro et al.[4] in 1996. To the best of our knowledge, 173 cases of ISFTs have been documented to date in the international English literature. Involvement of the central nervous system is rare, which may be due to the low content of true connective tissue elements. These lesions affect mostly adults and may involve both the cranial (including intraparenchymal and skull base locations) and the spinal (including nerve roots) meninges.

In the past, it was thought that ISFTs pursued a slow, indolent, and nonaggressive course; however, a growing body of literature based on longer follow-up times demonstrates an unpredictable clinical course and an uncertain prognosis. Anaplastic or malignant transformation of benign ISFTs resulting in multiple local and distant recurrences has been described.[5,6] In this article, we describe a series of 29 patients with ISFTs that showed an unpredictable clinical course regardless of histologic grade. Following a discussion of the specific clinical and imaging

Key words
- Anaplasia
- Hemangiopericytoma
- Intracranial solitary fibrous tumors
- Radiotherapy
- Recurrence

Abbreviations and Acronyms
HPC: Hemangiopericytoma
ISFT: Intracranial solitary fibrous tumor
SFT: Solitary fibrous tumor

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Table 1. Demographic and Clinical Characteristics of Patients in Series (2006–2015)

Case	Age (Years)/ Sex	Location	Symptoms	Treatment	Histopathology	RT	Recurrence/FU	*STAT6* Expression
1	42/M	Left pterional	Headache, double vision	GTR	HPC	Yes	No/108 months	Yes
2	40/M	Right parietal parasagittal	Left hemiparesis	GTR	HPC	Yes	No/60 months	Yes
3	36/M	Left parietal parasagittal	Headache	GTR	HPC	Yes	No/84 months	Yes
4	37/F	Torcular	Headache, vertigo	GTR	Fibrous tumor	No	No/56 months	Yes
5	55/F	Left free edge of tentorium	Vertigo, headache	GTR	HPC	Yes	No/72 months	No
6	59/M	Left orbit	Headache, left orbital tension and diplopia	GTR	Fibrous tumor	No	No/42 months	Yes
7	40/F	Right free edge of tentorium	Headache	GTR	Fibrous tumor	No	Yes at 5 months (redo GTR, RS); new recurrence at 21 months (redo RS), followed by progression; died 15 months later	No
8	41/M	Parietal bilateral middle third of SLS	Severe headache	GTR	HPC	Yes	Yes at 15 months (redo surgery); no recurrence at 36 months	No
9	39/F	Left APC (sigmoid sinus)	Headache, walking instability	NTR	Fibrous tumor	No	No/36 months	Yes
10	44/M	Torcular	Headache	NTR	Fibrous tumor	No	No/27 months	No
11	45/M	Left occipital (transverse sinus)	Headache, right homonymous hemianopia	GTR	Fibrous tumor	No	Yes at 24 months (redo GTR and RS histology of anaplastic lesion); no recurrence at 24 months	No
12	42/M	Frontal bilateral anterior third of SLS	Headache, progressive paraparesis	GTR	HPC	Yes	Yes at 7 months (redo GTR); new recurrence at 4 months (redo GTR and RS histology anaplastic lesion); new recurrence at 24 months; no progression since 12 months	No
13	47/M	Left APC	Vertigo, tinnitus, headache	NTR	HPC	Yes	Progression at 29 months (redo RS); stable at 40 months	No
14	49/M	Right occipitocerebellar (transverse sinus)	Headache, instability walking	GTR	Fibrous tumor	No	No/26 months	Yes
15	38/M	Right pterional	Headache, double vision	GTR	HPC	Yes	Yes at 22 months (redo surgery); no progression at 34 months	No
16	34/F	Right parietal parasagittal	Headache, left hemiparesis	GTR	HPC	Yes	No/19 months	Yes
17	57/M	Parietal bilateral middle third of SLS	Headache, right hemiparesis	NTR	Fibrous tumor	Yes	Yes at 16 months (redo surgery plus RS); new recurrence at 10 months; progression continued, still alive (very poor condition)	No
18	38/M	Frontal bilateral anterior third of SLS	Headache	GTR	HPC	Yes	No/16 months	Yes

RT, radiotherapy; FU, follow-up; M, male; GTR, gross total resection; HPC, hemangiopericytoma; F, female; RS, radiosurgery; SLS, sinus longitudinal superior; APC, angle ponto-cerebelleux; NTR, non-total removal; ILS, inferior longitudinal sinus; WHO, World Health Organization.

Continues

Table 1. Continued

Case	Age (Years)/ Sex	Location	Symptoms	Treatment	Histopathology	RT	Recurrence/FU	*STAT6* Expression
19	41/F	Bilateral occipital posterior third of SLS	Headache, double vision	NTR	Fibrous tumor	No	No/15 months	No
20	43/F	Bilateral cerebellar ILS	Headache, vertigo, unsteady gait	GTR	HPC	Yes	No/14 months	Yes
21	58/M	Right clival	Headache, double vision	NTR	HPC	Yes	No progression/14 months	Yes
22	35/M	Left spheno-orbital	Headache, double vision	NTR	HPC	Yes	No progression/12 months	No
23	42/M	Right temporal	Headache	GTR	HPC	Yes	No/12 months	Yes
24	37/F	Right orbit	Headache, double vision, exophthalmos	GTR	Fibrous tumor	Yes	Yes at 11 months (redo surgery plus RS); no recurrence at 12 months	No
25	54/M	Cerebellar (free margin of left tentorium)	Gait impairment, dizziness, headache, cerebellar static syndrome	GTR	Fibrous tumor	Yes	Yes at 28 months (RS [Gamma Knife; Elekta AB, Stockholm, Sweden]); no recurrence at 38 months from RS	Yes
26	60/M	Parietal (postcentral) parasagittal, left	Cutaneous head swelling	GTR	Fibrous tumor	No	Lost to FU at 6 months	No
27	58/M	Right orbit (posterior third)	Exophthalmos, impairment in looking upward	GTR	Fibrous tumor	No	No/35 months	Yes
28	43/M	Occipital external protuberance, torcular	Dizziness, headache, gait impairment	GTR	Fibrous tumor 2010/HPC (anaplastic, WHO III) 2016	Yes after second surgery	Yes at 66 months (redo surgery [GTR] plus RT); no recurrence 26 months after RT	Yes
29	59/M	Sphenoethmoidal with left predominance	Rapid decrease of left eye visual acuity	GTR	Anaplastic HPC	Yes	No/24 months	Yes

RT, radiotherapy; FU, follow-up; M, male; GTR, gross total resection; HPC, hemangiopericytoma; F, female; RS, radiosurgery; SLS, sinus longitudinal superior; APC, angle ponto-cerebelleux; NTR, non-total removal; ILS, inferior longitudinal sinus; WHO, World Health Organization.

features of the tumors, we focus on the natural history of these pathologies and the need for tailored management.

MATERIALS AND METHODS

This is a case series of 29 consecutive patients with an ISFT or hemangiopericytoma (HPC) treated at our institution during a 10-year period (from January 2006 to December 2015). All patients' clinical, surgical, and follow-up data were prospectively recorded in a database started in 2006, the year that a multidisciplinary neuro-oncology board was introduced in our institution. All patients underwent preoperative and postoperative magnetic resonance imaging and magnetic resonance angiography (first at 6 months postoperatively, then every year where applicable). All specimens obtained from histologically or immunohistochemically proven ISFTs or HPCs were recently retrieved and reassessed by neuropathologists not involved in the initial diagnosis. Specifically, all lesions included in this analysis were retrospectively regraded according to the 2016 World Health Organization classification. In selected cases, a second opinion was sought to resolve dilemmas and achieve consensus regarding the grading.

RESULTS

The 29 patients in this study included 21 men and 8 women, with a mean age of 45.28 years (range, 34–60 years). Mean follow-up after surgical management was 37.71 months (range, 6–108 months). Demographic and clinical characteristics of the study population are presented in Table 1.

Management

Of 29 patients, 22 had a gross total resection and 7 had a subtotal (>95% of the lesion) tumor resection; 19 patients underwent radiotherapy immediately in the postoperative period after discussion in our multidisciplinary neuro-oncology board (all 15 patients with HPC and 4 patients with solitary fibrous tumor with a subtotal resection) (Table 2). As such, 2 subgroups may be distinguished in this series: the first subgroup ($n = 15$ patients) included all patients who underwent radiotherapy after surgical excision; the second subgroup ($n = 14$ patients) included patients who did not receive adjuvant radiotherapy. This subclassification highlights 2 aspects: one pertaining to clinical management (as all patients with an initial diagnosis of HPC were referred for radiotherapy) and the other pertaining to local

Table 2. Descriptive Statistics of Study Population

Variable	Value
Population	
Total patients	29
Male patients	21 (72.4%)
Female patients	8 (27.6%)
Age, years, mean (range)	45.28 (34—60)
FU, months, mean (range)	37.71 (6—108)
STAT6 expression in population	
Yes	16 (55.2%)
No	13 (44.8%)
STAT6 expression according to histology	
HPC, grade II and III	10 (66.7%)
Benign fibrous tumor, grade I	6 (42.9%)
Histology	
HPC, grade II and III	15 (51.7%)
Benign fibrous tumor, grade I	14 (48.3%)
Resection	
GTR	22 (75.9%)
STR	7 (24.1%)
Postoperative radiotherapy	
Benign fibrous tumor	4/14 (28.6%)
HPC	15/15 (100.0%)
Total	19/29 (65.5%)
Patients with recurrences during FU	
Group with HPC (grade II and III)	4/15 (26.7%)
Group with benign ISFT (grade I)	6/14 (42.9%)

FU, follow-up; HPC, hemangiopericytoma; GTR, gross total resection; STR, subtotal resection; ISFT, intracranial solitary fibrous tumor.

aggressiveness of the lesions (as 4 patients with an initial diagnosis of low-grade fibrous tumor eventually had a recurrence requiring redo surgery and radiation treatment).

Recurrences

Four patients in the HPC group experienced a recurrence (Table 3) requiring redo surgery and/or radiosurgery. Their clinical response was satisfactory, AS they were recurrence-free at their last follow up (median follow-up of 35 months). In the 14 patients with an initial diagnosis of a benign ISFT, gross total resection was obtained in 10, whereas the subtotal resection achieved in the other 4 prompted a postoperative referral for adjuvant radiotherapy. Recurrences in the fibrous tumors group seemed to be associated with a worse prognosis than in the HPC group. Of 6 patients presenting with recurrences (Table 4), 1 patient died during the follow-up period, and another showed a continuous progression. A histologic diagnosis of an anaplastic transformation was made in another patient at the time of redo surgery (however, he is now progression-free). The histopathologic analysis of the specimens obtained from both surgeries suggests a grade II lesion already at the time of diagnosis. A flowchart of the evolution of the disease in our population is shown in Figure 1.

Survival Curves and Statistics

Survival curves for recurrence-free intervals were made to compare the recurrence-free intervals in patients with fibrous tumors with patients with HPCs. SAS University SAS Studio software (SAS Institute Inc., Cary, North Carolina, USA) was used. The Kaplan-Meier curve that was made is shown in Figure 2.

DISCUSSION

ISFTs are a rare and heterogeneous group of tumors including meningeal SFTs and HPCs.[7] These tumors were originally described extensively in the thorax, but their recognition in

Table 3. Recurrences in Hemangiopericytoma Group (Grades II and II)

Case	Age (Years)/Sex	Resection	Initial RT	Total FU (Months)	Time to Recurrence (Months)	Management	Outcome at Last FU	Last Procedure to Last FU (Months)
12	42/M	GTR	Yes	47	7, 11, 35	Redo surgery and RS	No progression	12
13	47/M	NTR	Yes	69	29	Redo surgery	No progression	40
8	41/M	GTR	Yes	51	15	Redo surgery	No progression	36
15	38/M	GTR	Yes	56	22	Redo surgery	No progression	34

RT, radiotherapy; FU, follow-up; M, male; GTR, gross total resection; RS, radiosurgery; NTR, non-total resection.

other parts of the body and particularly in the neuraxis has increased.[8,9] Their classification was modified in 2016 by the World Health Organization, and these tumors accordingly range from benign to malignant (Table 5).[10]

The histogenesis of SFTs was extensively debated (whether the origin is mesothelial or mesenchymal), but more recent immunohistochemical and electron microscopic studies favored the mesenchymal fibroblast-like cells origin hypothesis for both pleural and extrapleural SFTs.[11] Of note, SFTs can mimic other benign or malignant spindle-cell tumors, rendering histologic diagnosis difficult.[12] Although the main differential diagnosis of ISFT is fibrous meningioma, other benign and malignant lesions should be considered in the differential diagnosis, including schwannoma and sarcomas.[13] Typical histopathologic images of such tumors are shown in Figure 3.

Clinical Features

Similar to meningiomas, symptoms are mostly related to tumor location.[14] Although any age group can be affected (range, 11–73 years), these tumors usually occur in the fifth decade. Tumors occur equally in men and women.[15]

Radiologic Features

The preoperative diagnosis of ISFT solely based on radiologic features is challenging, if not impossible.[16] ISFTs are usually in close contact with the meninges and are characterized by isointensity on T1-weighted images and heterogeneous hypointensity on T2-weighted images.[12] ISFTs lack a reliable and specific neuroimaging sign; therefore, an index of suspicion can be raised only by awareness regarding this pathologic entity by a very cautious and rigorous observer.[17,18] Some authors described unspecific magnetic resonance imaging features that could point, among others, toward a suspicion of an ISFT, such as the so-called yin-yang sign, consisting of a patchy black-and-white pattern of alternating areas of hyperintensity and hypointensity on post-contrast T2-weighted scans.[18,19] The yin-yang sign probably reflects the staghorn vascularity and variations in cellularity of different areas of ISFTs.[20] Digital subtraction angiography of ISFTs most often demonstrates a moderately to highly vascularized lesion fed by either the external and/or internal carotid arteries or vertebrobasilar system, with a usual late and persistent tumor blush,[21-24] although hypovascularized tumors have also been seen.[16,21,25] Of note, we have not found a yin-yang sign in our series; nonetheless, some lesions showed a mixed

Table 4. Recurrences in Meningeal Fibrous Tumors Group (Grade I)

Case	Age (Years)/Sex	Resection	Initial RT	Total FU (Months)	Tine to Recurrence (Months)	Management	Outcome at Last FU	Last Procedure to Last FU (Months)
7	40/F	GTR	No	41	5, 26	Redo surgery and RS on first recurrence, salvage RS on second recurrence	Death at 41 months	15
24	37/F	GTR	Yes	23	11	Redo surgery and RS	No progression	12
11	45/M	GTR	No	48	24	Redo surgery and RS	No progression	24
17	57/M	STR	Yes	34	16, 26	Redo surgery on first recurrence, RS on second recurrence	Evidence of progression, poor general condition	8
25	54/M	GTR	Yes	66	28	RS	No recurrence	38
28	43/M	GTR	No	92	66 (with diagnosis of HPC WHO grade III)	Redo surgery and RT	No recurrence	26

RT, radiotherapy; FU, follow-up; F, female; GTR, gross total resection; RS, radiosurgery; M, male; STR, subtotal resection; HPC, hemangiopericytoma; WHO, World Health Organization.

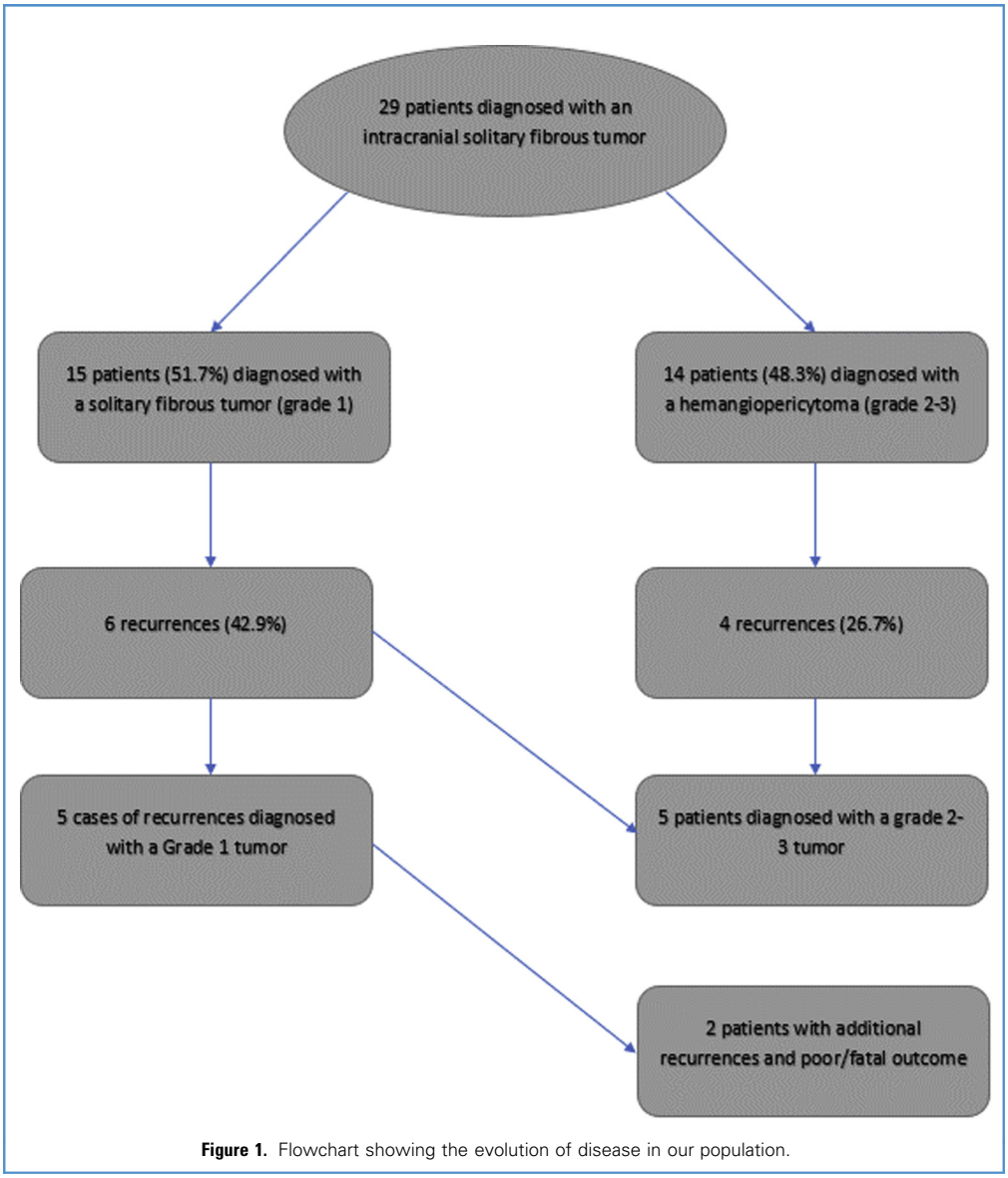

Figure 1. Flowchart showing the evolution of disease in our population.

hypointensity/hyperintensity pattern on T2-weighted scans, and areas of hypocellularity/hypercellularity were confirmed on histologic analysis.

Histopathologic Features and Prognosis

According to the new World Health Organization Classification,[25] a 3-tiered grading system is now used for determining the prognosis. Grade I defines benign tumors and corresponds to the classic SFT pattern (with hypocellular pattern and collagen). Both Grades II and III define malignant lesions (with <5 mitoses per 10 high-power fields for grade II lesions and >5 mitoses per 10 high-power fields for grade III lesions).[26]

From a molecular point of view, most SFTs and HPCs harbor a genomic inversion at the 12q13 locus, leading to fusion of the *NAB2* and *STAT6* genes. This fusion leads to *STAT6* nuclear overexpression that can be detected by immunohistochemistry.[26] The assessment of this fusion is now highly recommended to confirm the diagnosis. A negative result should prompt consideration of alternative diagnoses, and it should be indicated in the report when *STAT6* immunohistochemistry or *NAB2*/*STAT6* fusion cannot be assessed.

The other useful immunohistochemical characteristic is the expression of CD34, although it may be less intense in more aggressive lesions. The differential diagnosis includes both meningothelial and soft tissue neoplasms; these are much rarer tumors, and therefore advanced immunohistochemistry or molecular assay should be considered to reach a definitive diagnosis.[27,28] The immunohistochemistry studies performed in our

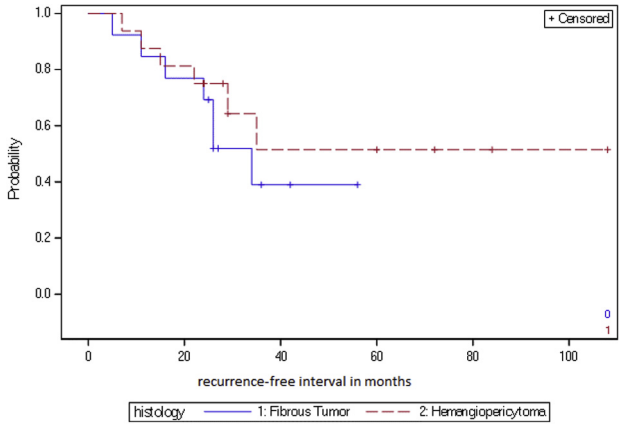

Figure 2. Kaplan-Meier curve representing the recurrence-free evolution of disease in patients with a meningeal fibrous tumor (*blue line*) and patients with a hemangiopericytoma (*red line*).

series suggest the importance of STAT6 expression in the characterization of ISFTs and their grading. STAT6 expression analysis is a supplementary and valuable tool in the clinician's armamentarium in conjunction with progesterone receptors and CD34.

Outcome and Survival

Incomplete surgical excision is currently considered one of the most important predictive factors of recurrence.[27] In the literature, of the 25 reported cases of ISFTs with recurrence and/or metastasis, at least 9 had undergone subtotal resection at time of the initial surgery. In our series, complete resection was achieved in 22 of 29 cases; immediate postoperative radiotherapy was performed in 6 cases after multidisciplinary neuro-oncology board discussion given the histologic diagnosis of HPC. Of note, the series described in this article shows an unpredictable outcome, despite gross total resection and adjuvant radiotherapy in cases with higher grade ISFTs (HPCs). More surprising is the bad, and sometimes dramatic, evolution seen in some of our patients with diagnosis of a benign grade I ISFT. Progression in ISFTs into higher grades has been rarely reported.[27] In 2017, Apra et al.[28] reported the first series of patients presenting with a progression of ISFTs. Given the results from our series, we cannot stress enough the importance of a strict follow-up protocol in the postoperative management of these tumors.

Malignant Transformation

Although not well described, malignant transformation of ISFTs should also be considered for initially benign ISFTs, which could transform into more aggressive tumors even after years of follow-up.[28] The role of the STAT6-DNA binding site has been abundantly highlighted: positive staining is highly sensitive and specific. Tumors exhibiting a full STAT6 site seem more prone to behave as benign SFTs, whereas tumors lacking the STAT6 binding site had more uncertain behavior (resembling low-grade sarcomas) and had more chances to exhibit a malignant phenotype.[29] As such, it is important to keep in mind that patients may require adjuvant radiation therapy (including radiotherapy and/or radiosurgery) not only depending on the extent of excision but also in light of the immunohistochemical/molecular pattern of their lesions.[29,30] The dichotomous distribution described in our series of benign and aggressive lesions into the 2 subgroups treated with and without adjuvant radiation treatment follows pretty well the pattern of positivity for STAT6 in 50% of the tumors excised. However, as previously described by others, no correlation was shown between those types and prognosis or recurrence-free survival.[29-31]

CONCLUSIONS

ISFTs are rare mesenchymal neoplasms originating in the meninges. Owing to their rare occurrence, ISFTs are often poorly recognized and remain a diagnostic challenge. The correct diagnosis of SFT can be made only by histopathology relying mainly on immunohistochemical staining, which is characterized by positive expression of CD34, Bcl-2 protein, and vimentin. Finally, although ISFTs are still considered benign lesions with very rare aggressive evolution, the present series has clearly shown that their clinical behavior is unpredictable despite the histology of a benign lesion with a low expression of Ki67. In fact, a good portion of lesions initially labeled as relatively benign histotypes would be regraded according to the 2016 World Health Organization Classification and considered as more aggressive lesions; equally, it is possible that the aggressivity of many lesions treated with radiotherapy had been initially overestimated. As shown by our study, this would in part explain the mixed behavior of this class of tumors, and it highlights the importance of relying on immunohistochemistry for a thorough definition of the management strategy.

Table 5. World Health Organization Classification of Intracranial Solitary Fibrous Tumors

Old Classification	2016 WHO Classification	Criteria	Common Pattern
Meningeal solitary fibrous tumor	Benign grade I fibrohyaline type	No mitosis	Staghorn vascularization; *NAB2-STAT6* fusion
Hemangiopericytoma	Intermediate grade II hypercellular type	<5 per 10 high-power fields	
	Malignant highly mitotic grade III	>5 per 10 high-power fields	

WHO, World Health Organization.

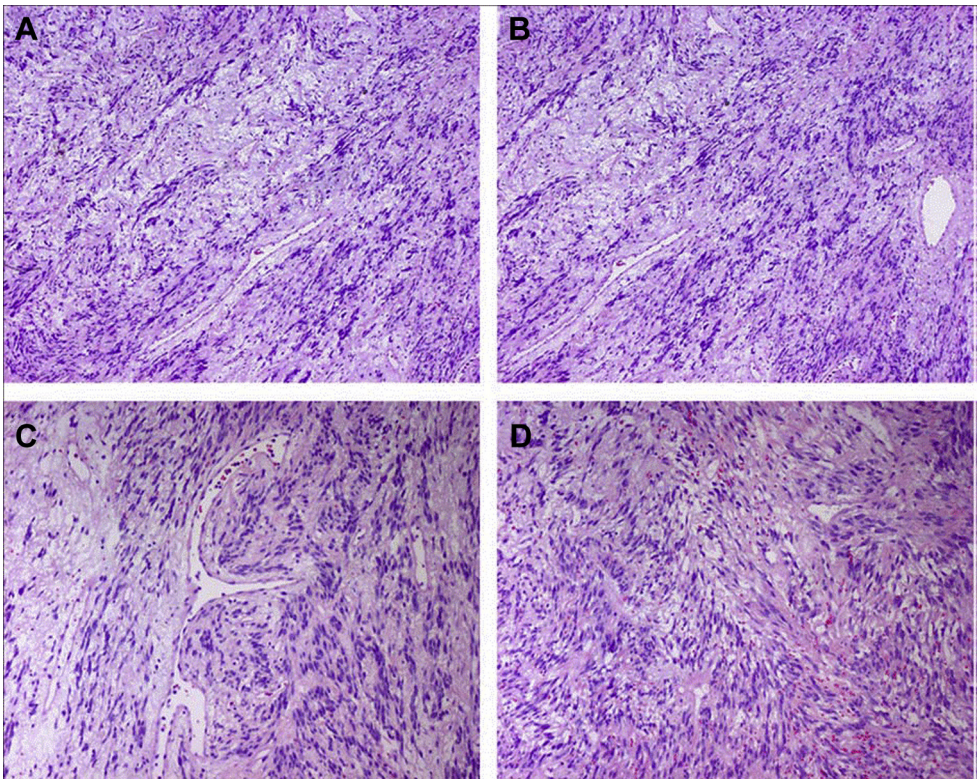

Figure 3. Histologically benign solitary fibrous tumor with unusual features. (**A** and **B**) Slight myxoid background (original magnification ×200). (**C** and **D**) Vaguely neural-like appearance with abortive palisading (original magnification ×200).

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